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September 12, 1962

PROPOSAL FOR DATA HANDLING SERVICES

Prepared By

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PROPOSAL FOR DATA HANDLING SERVICES

[redacted] proposes to perform all or a desired selection of the following services:

1. High acuity processing of original 35 and 70 mm film, copying or duplicating enlarging of these films as required, in the existing facility at 331 West 44th Street, New York City. The facilities capability is described in Appendix A [redacted] Photographic Processing Capability."

2. The measurement of star images and associated fiducial marks. The measurements will be accomplished with instrumentation and by procedures described in Appendix B.

3. The computation of tip, tilt and yaw with respect to a defined geocentric reference system for each star camera frame and their transfer by calibration data to the optical axis and reference frame of a rigidly connected ground camera. The computational processes will be accomplished upon the inputs of the measurements of Paragraph 2, and upon orbit ephemeris data and camera calibration data to be furnished by the customer. The computational processes, programs and reference definitions are described in Appendix C.

Cost estimates for the services specified in the preceding paragraphs 1 through 3 and corresponding descriptive Appendices A through C are attached.

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APPENDIX A

Autometric Photographic Processing Capability

[redacted] operates a complete photographic processing laboratory STAT [redacted] The laboratory contains all equipment STAT required for the automatic development of roll film up to 9" width as well as a full complement of tray development facilities.

A positive pressure is maintained throughout the photo lab. Temperature is controlled to $70^{\circ} \pm \frac{1}{2}^{\circ}$ and humidity is controlled to 50% ± 5%. Water is filtered and temperature controlled to $68^{\circ} \pm \frac{1}{2}^{\circ}$. Modern air filtering is employed to insure a dust free area.

All photographic procedures are sensitometrically controlled.

<u>Sensitometric Equipment:</u>

F-M-15 Sensitometer

Weston Densitometer

The laboratory contains the following photographic reproduction equipment which may be applicable to the attached proposal:

1. Bell and Howell 35 mm Model D printer.

   Morse - Negative, positive, reversal, 35 mm processing machine.

   Movieola - 35 mm Viewer

   Acme 5 inch 70 mm to 35 mm optical printer. This machine can be precision positioned for various enlargement factors on the 35 mm format.

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2. Log Etronic strip printer, fully automatic electronic dodging and exposure control. EH-6 modified, 70 mm processing machine circulating solutions, temperature controlled.

3. Automated Zeiss SEG V which assumes proper rectification alignment through punch card inputs.

4. Bausch and Lomb Horizontal Photogrammetric Rectifier, capable of handling tilts from 0^{o} to 70^{o} with 2 times enlargement, 2 lenses of 113 mm and 175 mm focal length for rectifying 6 inch and 6-12 inch photography respectively.

5. Wild VG 1 Enlarger, capable of enlargements from 0.75 to 7 times; 150 mm Reprogon wide angle (74^{o}) enlarging lens.

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APPENDIX B

Measurement of Star Images

The Stellar Coordinate Reader at [redacted] facility STAT is the measuring machine to be used in scaling distances of stellar imagery with respect to fiducial marks on film negatives. It permits evaluation of formats of less than 5 x 3 inches. The measuring system consists of three basic components:

1. The measuring unit composed of film holders, drives, and viewing screen.
2. The electronic racks containing the necessary electronics for operation.
3. The recording unit containing an auxiliary data panel and an IBM 526 card punch.

The Stellar Coordinate Reader has a measuring precision of 1 micron and a measuring accuracy of 3 microns.

The design of this machine has eliminated much of the fatigue factor associated with conventional measuring units. Two of the functional designs contributing to ease of operation are the automatic X-Y drives by a "joy stick" arrangement and the automatic lock-on system to point imagery by an electronic servo system.

Operational procedures for measuring are carried out swiftly and easily by one operator seated at the console of the measuring unit. At this position, the operator has full view of the measuring area projected at approxi-

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mately 24X enlargement on a 30" x 30" screen; he also has access to all controls for full operation of the measuring system.

The film rolls are loaded from the rear of the measuring unit and are held to the film platen by a film clamp and vacuum system. Frames on the film rolls are moved into position by film drives controlled from the console panel. Auxiliary data for descriptive and computer uses for each frame are set by switches in the Aux Data panel of the recording unit.

A typical measuring program for one frame requires the measurement of four fiducials, a number of stellar points, and repeat measurements of the same fiducials for the purpose of providing an automatic computer check on the quality of the measurements. The data output is in card format with two distinct types of recorded measurements--fiducial measurements and stellar measurements. These measurements are distinguished from each other through auxiliary data that are programmed into the recording unit and automatically punched into the data cards ahead of the measurements.

Measurements are recorded by control switches on the console panel in a programmed sequence for input into digital computers. The switches are activated by the operator when the servo has automatically locked-on to the point that is to be measured. The "joy stick" is used to drive the stellar imagery into the field of sensitivity for automatic lock-on by the servo system. The servo system is designed to lock-on to black dots on a clear background,

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therefore negative star images are required for proper operation.

It is estimated that the measuring process consisting of four fiducials - six image points - four fiducials will take ten minutes per frame including all auxiliary data settings, film changes, etc.

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APPENDIX C

θ $\phi\Omega$ ψ

pitch, roll

Computation of Tip, Tilt, and Yaw

The data required to determine platform orientation are: the film coordinates of the fiducial marks and of three identified and any additional number of non-identified stars, the time of exposure, the vehicle ephemeris, and sufficient data to determine the approximate field of view of the star camera in celestial coordinates of right ascension and declination.

In order to utilize the existing computer programs, the format of the ephemeris magnetic tape must be identical to that used in existing programs. ?

The sidereal orientation of the star taking camera is obtained as follows:

a) By making use of the fiducial measurements, the measured coordinates are reduced to the camera calibration system and are further corrected to remove the effects of radial lens distortion and aberration.

b) A preliminary orientation is computed from the corrected film coordinates of three measured stars which have also been identified in a star catalogue such as the Boss Catalogue. The program then identifies and computes the apparent place of all measured stars for the instant of exposure, and computes a final camera orientation utilizing all the measured star images and their sidereal geocentric coordinates.

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A matrix defining the relative orientation of ground camera axes with respect to the star camera system must be supplied to the program. Upon this information the program will then furnish the sidereal geocentric direction cosines of the ground system.

Utilizing the time of exposure, these direction cosines are referred to the Greenwich system, and using the geographic coordinates and azimuth from the ephemeris, they are referred to the local vertical system. At this point, it is possible to compute the yaw, pitch and roll angles as defined in the following paragraph. It should be recognized that the accuracy obtainable is limited by the accuracy of the determination of the sub-satellite point. If the sub-satellite position is in error by one mile, the resulting angular error of the orientation will be on the order of one minute of arc.

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Coordinate System

1) **Sidereal geocentric:** $\bar{i}_1$, $\bar{j}_1$, $\bar{k}_1$

Origin: the geometric center of the reference ellipsoid

$\bar{k}_1$ is a unit vector at the origin, parallel to the axis of rotation of the earth, and directed toward the north pole.

$\bar{i}_1$ is a unit vector perpendicular to $\bar{k}_1$ in the direction of the vernal equinox

$\bar{j}_1$ is a unit vector perpendicular to the plane of $\bar{i}_1$ and $\bar{k}_1$ so as to form a right handed system.

2) **Local Vertical:** $\bar{i}_2$, $\bar{j}_2$, $\bar{k}_2$

Origin: The latitude and longitude of the sub-satellite point on the reference ellipsoid

$\bar{k}_2$ is the unit normal to the reference ellipsoid at the sub-satellite point, directed toward the vehicle

$\bar{i}_2$ a unit vector determined by normalizing the projection of the satellite velocity vector onto the plane tangent to the reference ellipsoid sub-satellite point

$\bar{j}_2$ is determined as in 1)

This local vertical system may be obtained from 1) by performing the following rotations in succession:

a) about k through the angle $\alpha = GST + \lambda$. (α = the right ascension of the vehicle at the instant of exposure). This rotation results in a set of new $\bar{i}_1$, $\bar{j}_1$ vectors.

b) about the new $\bar{j}_1$ axis through $(\frac{\pi}{2} - \varphi)$, where $(\frac{\pi}{2} - \varphi)$ is the geographic co-latitude of the sub-satellite point). This rotation results in a set of new $\bar{j}_1$, $\bar{k}_1$ vectors.

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c) about the new $\overline{k}_1$ axis through the angle (π - A). A is the azimuth from north and is measured clockwise as positive. A is given in the vehicle ephemeris.

3) Platform System: $\overline{i}_3$, $\overline{j}_3$, $\overline{k}_3$

This is the system the orientation of which is desired. It is completely defined by specifying a relative orientation matrix relating it to the star taking camera. For the purpose of this analysis, the coordinate system will be assumed to be a right handed system fixed with respect to the platform.

The platform system may be obtained from the local vertical system by successive rotations about:

1) the $\overline{k}_3$ axis through the angle ψ (yaw)

2) the new $\overline{j}$ axis through the angle θ (pitch)

3) the new $\overline{i}$ axis through the angle Ω (roll)

Transformation Matrices

1) The matrix of direction cosines of the Sidereal system with respect to the local vertical system is

$$V = \begin{pmatrix} -\sin\alpha\sin A-\cos\alpha\sin\varphi\cos A & \cos\alpha\sin A-\sin\alpha\sin\varphi\cos A & \cos\varphi\cos A \\ \sin\alpha\cos A-\cos\alpha\sin\varphi\sin A & -\cos\alpha\cos A-\sin\alpha\sin\varphi\sin A & \cos\varphi\sin A \\ \cos\alpha\cos\varphi & \sin\alpha\cos\varphi & \sin\varphi \end{pmatrix}$$

2) The matrix of direction cosines of the vehicle system with respect to the local vertical system is

$$H=(h_{ij})= \begin{pmatrix} \cos\psi\cos\theta & -\sin\psi\cos\Omega+\cos\psi\sin\theta\sin\Omega & \sin\psi\sin\Omega+\cos\psi\sin\theta\cos\Omega \\ \sin\psi\cos & \cos\psi\cos\Omega+\sin\psi\sin\ \sin\Omega & -\cos\psi\sin\Omega+\sin\psi\sin\ \cos\Omega \\ \sin & \cos\theta\sin\Omega & \cos\theta\cos\Omega \end{pmatrix}$$

Letting S be the matrix of direction cosines of the vehicle axes in the sidereal system we have

$$H = V\ S = (h_{ij})$$

and the roll, pitch and yaw angles may be computed as follows:

$$= \sin^{-1} (h_{31})$$

$$= \tan^{-1} \left(\frac{h_{21}}{h_{11}}\right)$$

$$= \tan^{-1} \left(\frac{h_{32}}{h_{33}}\right)$$

θ will be determined by its principle value, and the quadrants of ϕ and Ω will be determined by quadrant analysis.

As a check on the computation, the H matrix may be recomputed from the literal values of its entries and compared element for element against the h_{ij} given above.

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